International Journal of Civil, Structural,
Environmental and Infrastructure Engineering
Research and Development (IJCSEIERD)
ISSN(P): 2249-6866; ISSN(E): 2249-7978
Vol. 5, Issue 5, Oct 2015, 41-50

STRENGTH AND SORPTIVITY STUDY OF COMBINED POWDER AND VMA TYPE SELCONSOLIDATING CONCRETE WITH SILICA FUME AND CRUSHER DUST

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ABSTRACT

The robustness of self-consolidating concrete (SCC) is enhanced by the addition of powder as well as viscosity modifying agent (VMA). The strength and durability properties of such combined powder and VMA type of SCC must be influenced by the reactivity of powder used and other mixture proportions. An attempt has been made in this investigation to study the influence of reactive silica fume and inert crusher dust as different powders in SCC. The SCC mixes were designed for M25, M35, M45 and M55 grades and tested for fresh properties, compressive strength, split tensile strength, sorptivity and chloride ingress. It was observed that the SCCs with silica fume produced better strength and durability than the SCCs with crusher dust and the difference was remarkable.

KEYWORDS: Crusher Dust, Durability, Silica Fume, Sorptivity, SCC

INTRODUCTION

Self-consolidating concrete is one of the newest forms of high performance concrete available today. SCC is a material that meets a unique combination of performance and uniformity requirements that cannot always be achieved using conventional constituents and usual construction practices (Hossain K and Lachemi M. [1]). Due to enhanced rheological properties of SCC and its placing method into construction elements, it provides number of benefits both to the environment and to the contractors e. g., faster construction, better surface finish, reduced noise level and safer working environment (Turk Kazim et al.[2]). Depending upon the manufacturing method SCCs can be classified as

- Powder Type: Additional powder other than cement is added in this type to maintain homogeneity and avoid segregation which can be caused due to flowability of SCC. The powders can either be inert like crusher dust, limestone powder or reactive pozzolanic like fly ash, silica fume, ground granulated blast furnace slag, rice husk ash etc.
- VMA Type: To enhance the segregation resistance and to increase viscosity viscosity modifying agent instead of powder filler is used in this type of SCC.
- Combined Powder and VMA type: Both powder and VMA are used in this type of SCC to avoid segregation. The addition of VMA also imparts robustness to the SCC.

Though SCC has been reported as high performance concrete its durability must be checked for different mineral admixtures which are added as powder fillers. In relation to durability, concretes are appraised through several properties, among them capillary sorptivity, whose importance is allied to the factor that this is the first phenomenon of transport of aggressive agents that takes place in concrete (Oliveira L. A. et al [3]). Martys and Ferraris [4] have shown that the

sorptivity coefficient is essential to predict the service life of concrete as a structure and to improve its performance. In addition to sorptivity the assessment of ability of chloride ions to penetrate the concrete can be useful information for design as well as quality control purposes. The penetration of the concrete by chloride ions, however, is a process which may be affected by the paste quality in SCCs. It cannot be determined directly in a time frame that would be useful as a quality control measure but the comparison of performance of different mineral admixtures will definitely help to make the choice among them.

In this work the combined type of SCC was investigated for strength and durability properties. Effect of use of silica fume and use of crusher dust on mechanical properties like compressive strength and split tensile strength and durability properties like sorptivity and chloride ingress was studied.

EXPERIMENTAL PROGRAMME

Materials

Cement: Ordinary Portland cement of grade 53 conforming to the IS 8112:1989 with specific gravity 3.12 was used for all the mixes.

Fine Aggregate: River sand conforming to zone II of IS 383:1970 having a specific gravity 2.52 was used as fine aggregate (F A).

Coarse Aggregate: The coarse aggregate (C A) had a maximum size of 16 mm. The fractions of coarse aggregate used were: 10 % of it was passing through 10 mm IS sieve and retaining on 4.75 mm IS sieve, 60 % of it was passing through 12.5 mm IS sieve and retaining on 10 mm IS sieve and 30 % of it was passing through 16 mm IS sieve and retaining on 12.5 mm IS sieve. The specific gravity of the coarse aggregate was 2.67.

Superplasticiser: The superplasticiser used in this study was Glenium B233 procured from BASF India Limited. It is based on modified polycarboxylic ether. It complies with ASTM C494 Types F and IS 9103:1999.

Viscosity Modifying Agent: The Viscosity Modifying Agent reduces the possibility of segregation and becomes essential ingredient when adequate paste volume is not present in the SCC. The VMA used to manufacture both type of SCCs was Glenium Stream 2 procured from BASF India ltd.

Water: Clean potable water available in the laboratory was used for mixing the concrete.

Silica Fume: Silica fume improves rheological, mechanical and chemical properties. It improves the durability of the concrete by reinforcing the microstructure through filler effect and reduces segregation and bleeding. It also helps in achieving high early strength. Silica fume of specific gravity 2.2 was used in this study. Chemical composition of silica fume is given in table 1. Silica fume was obtained from ELKEM India, Mumbai.

Table 1: Chemical Composition of Silica Fume

Sr. No.	Constituents	Quantity (%)
1.	SiO_2	91.03
2.	Al_2O_3	0.39
3.	Fe_2O_3	2.11
4.	CaO	1.5
5.	LOI	4.05

Quarry Dust: Quarry dust is used as an inert powder. It has been obtained from stone crusher; Quarry dust of specific gravity 2.5 passing through 150µ sieve is used.

Mix Proportioning of SCC

The mix proportion was done based on the method proposed by Nan-Su et al. [5]. The mix designs were carried out for concrete grades 25, 35, 45 and 55. This method was preferred as it has the advantage of considering the strengths of the SCC mix. In BS type of mixes silica fume was used as powder filler and in BD type of mixes crusher dust was used as powder filler. The final mix proportions have been shown in table 2.

All the ingredients were first mixed in dry condition. Then 70% of calculated amount of water was added to the dry mix and mixed thoroughly. Then 30% of water was mixed with the super plasticizer and added in the mix. A pan mixer of capacity 100 kg was used for mixing.

Then the mixes were checked for self-consolidating ability by slump flow test, v-funnel test, L-box test and GTM screen test as suggested by EFNARC [6]. On satisfying the criteria of self-consolidating ability the mixes were tested for compressive strength. Necessary changes were made in the mix proportions to achieve required fresh and strength properties.

Table 2: Mix Proportions in kg per Cubic Meter Concrete

Type of SCC	Specimen	Grade	Cement	S. F.	C. D.	F A	C A	Water	SP	VMA
Combined Type (Silica Fume)	BS1	M25	215	115	0	960	813	149	5.81	0.086
	BS2	M35	258	102	0	960	813	162	5.04	0.108
	BS3	M45	311	83	0	960	813	156	7.36	0.079
	BS4	M55	357	63	0	960	813	147	8.06	0.084
Combined Type (Crusher dust)	BD1	M25	258	0	102	960	813	162	4.32	0.108
	BD2	M35	311	0	83	960	813	156	4.84	0.079
	BD3	M45	357	0	63	960	813	147	5.04	0.084
	BD4	M55	408	0	47	960	813	136	5.43	0.091

Self Consolidating Ability Tests on SCC Mixes

Various tests were conducted as per EFNARC [6]on all the mixes to check for their acceptance and self-consolidating ability properties. The tests included slump flow test and V-funnel tests for checking the filling ability, L-box test for passing ability and GTM screen stability test for segregation resistance. The mixes were checked for the SCC acceptance criteria EFNARC [6].

Casting and Curing of Specimens

After checking the self-consolidating ability of the mix it was poured into the moulds of different sizes. The moulds were covered with wet gunny bags for 24 hours after casting and the specimens were then immersed in water for curing after demoulding. Cubes of 150×150×150mm were cast for test of compressive strength. Cylindrical specimens of height 300 mm and diameter 150 mm were cast for split tensile strength. All durability tests were performed on 100×100×100mm cube specimens. After 28 days of curing the specimens were taken out of curing tank for different tests in hardened state.

Tests for Strength

Compressive Strength

Cube specimens of size 150×150×150mm were tested for average compressive strength at 3 days, 7 days and 28 days according to IS 516. Three specimens were tested per test.

Split Tensile Strength

The cylindrical specimen was placed and loaded in diametrical compression in the compression testing machine of capacity 1000kN, so as to induce transverse tension. The specimen was loaded till vertical crack along the diameter splits the cylinder and the maximum load was noted. Three specimens were used per mix. The split tensile strength was then calculated as below

$f_{ct} = 2P/\pi DL$

Where,

f_{ct} –Split tensile strength

P -Splitting Load

D –Diameter of the cylindrical specimen

L –Length of the cylindrical specimen.

Durability Tests

The durability tests were carried out on cube specimens after 28 days of curing. For each test of each mix three specimens were tested and average of the three has been shown.

Sorptivity Test

The test for water absorption by capillary action (sorptivity) was carried out to determine the sorptivity coefficient of concrete specimens which were preconditioned in oven at 105^0C for 24 hr. and then allowed to cool down at room temperature for 24hr to achieve a constant moisture level. Then, four sides of the concrete specimens were sealed by electrical tape keeping two opposite sides exposed to avoid evaporative effect as well as to maintain uniaxial water flow during the test. Before locating the specimens on water, their initial weight was recorded. One face of specimen was in contact with water. Only 5mm depth of the specimen was submerged in water. The water absorption at predefined intervals was noted by taking weight. Procedure was repeated, consecutively at various time intervals like 15 min., 30 min., 1 hr, 2 hr, 4 hr, 6 hr, 24 hr, 48 hr and 72 hr. Sorptivity coefficient was calculated by the following expression. It is given by the slope of the sorptivity curve when it gets stabilised.

$S = (Q/A)/\sqrt{t}$

Where,

S = Sorptivity (cm/$s^{1/2}$)

Q = Vol. of water absorbed in cm^3

A = Surface area in contact with water in cm^2

t = the time (s)

The Chloride Ingress

In the presence of chloride ions the steel reinforcing bars are more prone to corrosion. The test for chloride ingress was carried out in this study using colorimetric technique. The cube specimens after 28 days curing were immersed in 3% NaCl solution for another 28 days representing the exposure to saline or sea water. The cubes were then taken out of chloride solution and split. The $AgNO_3$ solution (0.1N) was sprayed on the exposed area after splitting. When silver nitrate solution was sprayed on a concrete containing chloride ions, a chemical reaction occurred. The chlorides bind with the silver to produce silver chloride, a whitish substance. In the absence of chlorides, the silver instead bonds with the hydroxides present in the concrete creating a brownish colour. A whitish colour at the border of specimen shows the depth of penetration. It was measured with the help of Vernier Calliper along all four borders of each specimen and the average was taken. The depth of chloride ingress measured by this method is only a quantitative measure and does not give any idea about the chloride ion concentration.

RESULTS AND DISCUSSIONS

Fresh Properties

The results of fresh properties of all types of SCC have been shown in Table 3. It can be observed that these mixes have passed all the tests deployed to assess the self-consolidating ability. These properties are influenced by dosage of superplasticiser, VMA and volume of coarse aggregate and fine aggregate as well. Still it has been observed that slump flow values of SCC with CD are better than SCCs with SF. It is to be noted that no correlation could be established among results of other tests on fresh SCC. This is conforming to the results shown by Soo-Duck Hwang et. al. [7].

Table 3: Fresh Properties of All Mixes

Specimen	Slump Flow (mm)	V-Funnel (sec)	L-Box h1/h2	GTM Screen %
BS1	653	8.7	0.86	7.39
BS2	712	9.45	0.91	11.93
BS3	684	10.7	0.89	8.63
BS4	692	10.3	0.93	8.79
BD1	805	8.33	0.96	14.35
BD2	759	11.01	0.81	4.7
BD3	695	10.8	0.83	13.6
BD4	721	11.8	0.89	10.52

Hardened Properties

Compressive Strength and Split Tensile Strength

The results of strength properties have been shown in Table 4. In BS type of SCC 47 to 56.4% of 28 days compressive strength was achieved at the age of 3 days as compared to 44.6 to 59.9% in BD type. Also 69.4 to 79.3% of 28 days compressive strength was achieved at the age of 7 days in BS type as compared to 65.3 to 76.6% in BD type. BS type of SCC attained higher compressive strength as compared to BD types of same grade. Most research workers agree that the C-S-H formed by the reaction between silica fume and $Ca(OH)_2$ appears dense and amorphous (Fan, Y. F. et al., [8]). The compressive strength of all BD type mixes is much less than BS type because of inertness of the former.

The split tensile stress of BS type mixes shown the same pattern as compressive strength. The ratio$f_{cc}/f_{ct}$of all BS type mixes is greater than BD type of same grade.

Table 4: Compressive Strength and Split Tensile Strength

Type of SCC	Specimen	Compressive Strength in Mpa			Split Tensile Strength in Mpa (f_{ct})	Ratio of f_{cc}/f_{ct}
		3 Days	7 Days	28 Days (f_{cc})		
Combined Type (Silica Fume)	BS1	19.38	32.69	41.26	4.19	0.101
	BS2	31.34	39.13	56.35	5.58	0.0990
	BS3	34.56	43.67	61.32	5.79	0.0944
	BS4	39.82	51.98	71.67	6.27	0.0874
Combined Type (Crusher dust)	BD1	15.98	20.44	26.67	2.45	0.0918
	BD2	18.67	24.44	35.35	3.21	0.0908
	BD3	20.31	29.72	45.53	3.97	0.0871
	BD4	26.31	41.15	56.36	4.19	0.0743

Correlation between Compressive strength and Split Tensile strength: The results of the regression analysis have been shown in table 5. Both the trend lines shown in Fig. 1 are second degree polynomial curves with values of coefficient of correlation above 0.93 which indicates that the correlation is very good. The curved nature of trend lines suggests that for higher compressive strengths the f_{ct}/f_{cc} ratio reduces as compared to lower strengths. This variation has been found for both types of SCCs. The top line of BS type shows that the tensile strength of this type is higher as compared to the same of corresponding compressive strength of BD types of SCCs. It can be attributed to packing effect, pozzolanic action of SF, best quality of transition zone between aggregate surface and the hydrated phase. The bond between the hydrated C-S-H gel and aggregate is strongest in this case and weaker in case of BD type.

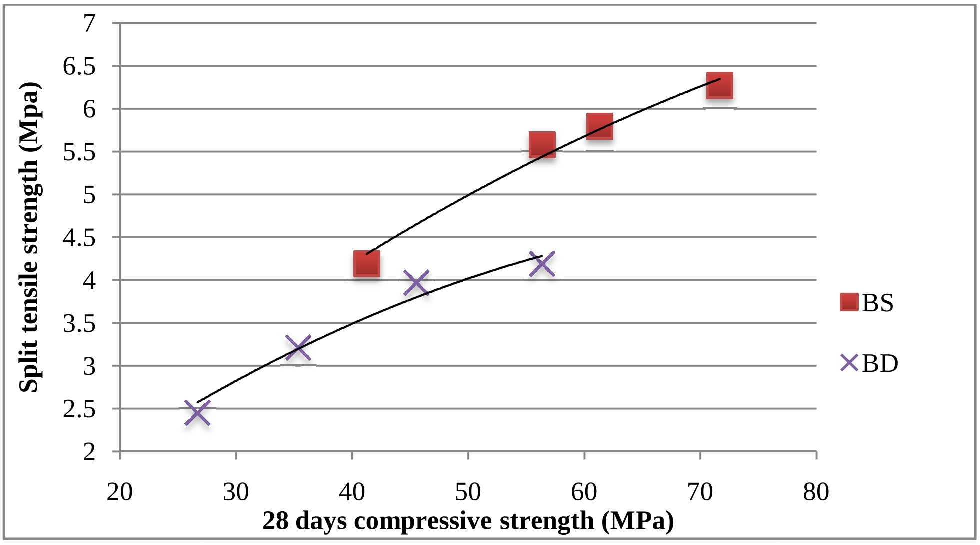

Figure 1: Correlation Between 28 Days Compressive Strength and Split Tensile Strength.

Table 5: Result of Regression Analysis for Correlation between 28 Days Compressive Strength and Split Tensile Strength

Type of SCC	Y = Split Tensile Strength (Mpa) X = 28 Days Compressive Strength (Mpa)	Coefficient of Correlation
BS	$y = -0.002x^2 + 0.124x$	$R^2 = 0.957$
BD	$y = -0.002x^2 + 0.130x$	$R^2 = 0.931$

DURABILITY TESTS

Sorptivity Test and Chloride Ingress Test

The results of sorptivity and chloride ingress tests are represented in Table 6. It can be observed that BS type SCC has shown lesser values of sorptivity coefficient as well as chloride ingress. The sorptivity of BD type mixes is in the range of 2 to 3 times as that of BS type of corresponding grades. The chloride ingress in BD type has been found to be 6 to 8 times of that in BS type. These results show that the microstructure of BS type SCCs must be much better and denser than that of the BD type. Hence BS type of SCCs can be assumed to be more durable than BD type of corresponding grades.The variation of sorptivity with $f_{cc}$of both type of SCCs has been demonstrated in figure 2 and it can be observed from this graph that for higher grades of SCCs the variation is small as compared to that at lower grades.

Table 6: Results of Sorptivity Test

Type of SCC	Specimen	Sorptivity (cm/s$^{1/2}$)	Chloride Ingress (mm)
Combined Type (Silica Fume)	BS1	0.00159	2.4
	BS2	0.00153	1.6
	BS3	0.00139	1.2
	BS4	0.00119	0.8
Combined Type (Crusher dust)	BD1	0.00381	13.5
	BD2	0.00354	10.6
	BD3	0.00326	7.8
	BD4	0.00305	5.4

Correlation of Sorptivity and 28 Days Compressive Strength: The trend lines shown in Figure 2 shows same trend. The trend line of BS type is far below the trend line of BD type which indicates the effect of improved microstructure of C-S-H gel, best particle packing effect in SCC with SF.

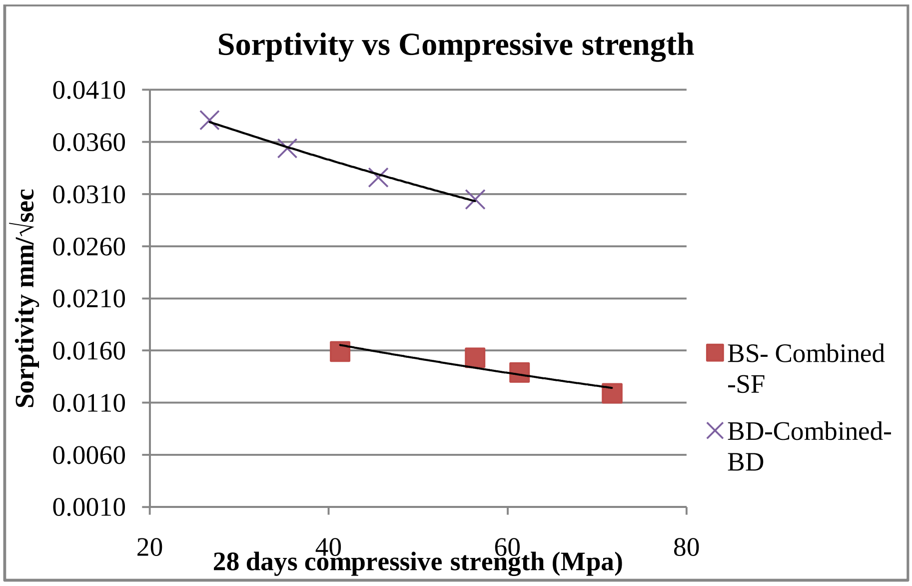

Figure 2: Correlation of Sorptivity Coefficient and 28 Days Compressive Strength

Regression analysis: The results of regression analysis are shown in Table 7. Both the equations are exponential functions with R^2 values more than 0.845 hence the correlation between sorptivity coefficient and compressive strength can be said to be good.

Table 7: Result of Regression Analysis for Correlation Betweensorptivity Coefficient and 28 Days Compressive Strength

Type of SCC	Equation(Y=Sorptivity Coefficient in $Mm/Sec^{0.5}$, X= 28 Days Comp Strength in Mpa)	Correlation Coefficient (R^2)
BS	$y = 0.0243e^{-0.009x}$	0.845
BD	$y = 0.0463e^{-0.008x}$	0.995

Correlation between chloride ingress and compressive strength: Figure 3 shows the variation of ingress of Cl^- ions with compressive strength of each type of SCCs. The ingress of Cl^- ions is very small in SCCs with silica fume. The equations of the trend lines in the form of polynomials and values of R^2 as the result of the regression analysis are shown in Table 10. It can be observed that very good correlation has been obtained as the value of R^2 is almost equal to one for both the trend lines.

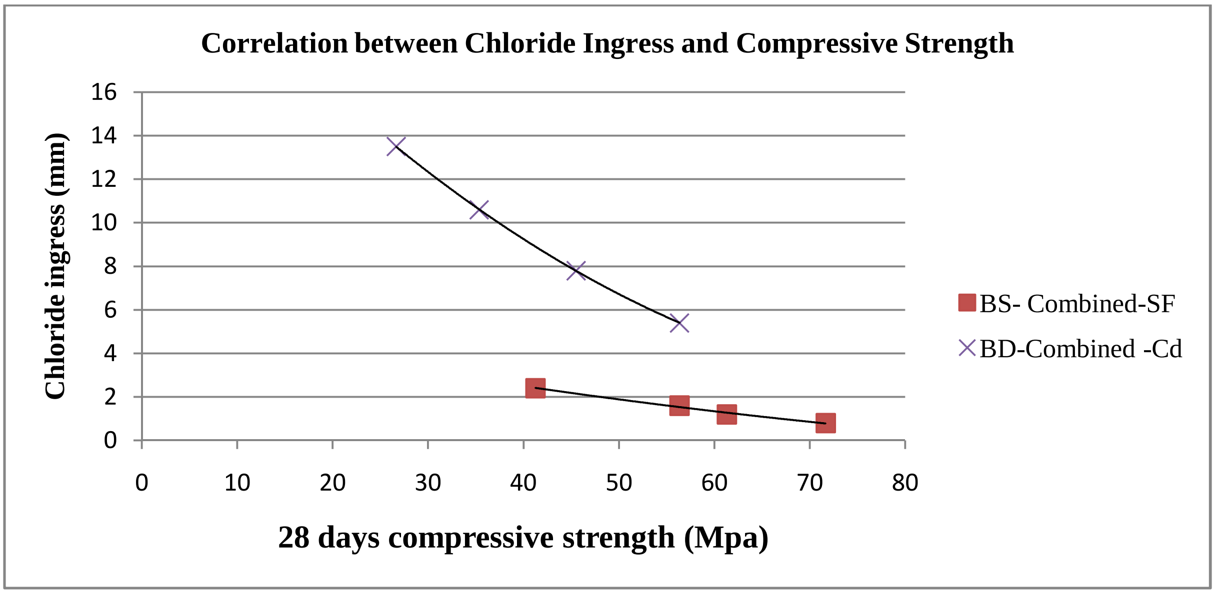

Figure 3: Correlation between Chloride Ingress and Compressive Strength

Table 10: Regression Analysis Results of Chloride Ingress

Type of SCC	Y=Chloride Ingress in Mm, X= 28 Days Compressive Strength in Mpa	Correlation Coefficient (R^2)
BS	$Y = 0.0001x^2 – 0.087x + 5.499$	$R^2 = 0.992$
BD	$y = 0.002x^2 – 0.504x + 24.96$	$R^2 = 1$

CONCLUSIONS

- It can be concluded that SCC with silica fume produces more strength with less cement content as compared to SCC with crusher dust.
- The tensile strength of SCCs with silica fume is also better than that of SCCs with crusher dust of same compressive strength.
- The compressive and tensile strength can be well correlated for both types of SCCs.
- The durability of SCCs with silica fume is much higher than that with crusher dust.

- The durability increases with the strength for both types of SCCs.
- The combined type of SCC with silica fume is more suitable for aggressive environmental exposure than the same with crusher dust.
- The compressive strength can be correlated with sorptivity as well as chloride ingress for both types of SCCs

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